Low p-type contact resistance using Mg-doped InGaN and InGaN/GaN superlattices

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Recent significant progress in growth of group-III nitride-based semiconductors by metalorganic vapor phase epitaxy has made it possible to realize InGaN-based light emitting diodes and laser diodes. However, it is difficult to grow p-type GaN with high hole concentration due to relatively deep acceptor level and there are no appropriate metals having large work functions, resulting in high p-type contact resistances. To further improve the device performances, one of the important problems is to obtain the low-resistance ohmic contacts to p-type materials. To date, the metallization schemes and surface treatments strongly affected the contact resistances, [1] resulting in the order or less than 10^{-4} Ωcm^2. From the viewpoints of high hole concentration layers, p-type AlGaN/GaN superlattices (SLs) were used to obtain low contact resistance. [2] Recently, we realized p-type InGaN with hole concentrations above 10^{18} cm^{-3} and p-type InGaN/GaN SLs with those above 10^{19} cm^{-3}. [3,4] In the GaAs system, a heavily doped narrow band-gap InGaAs has been widely used as a cap layers, because InGaAs has a narrower band-gap energy (E_g) than GaAs, and an InGaAs cap layer reduces both the contact potential barrier and the contact resistance. Therefore, InGaN having narrower band-gap than GaN is expected to be used as the low-resistive contact layers of group-III nitride-based semiconductors. So far, for n-type contacts, InN/GaN short-period SLs have been demonstrated for the cap layers. [5] In this work, we investigated p-type InGaN and InGaN/GaN SLs as p-type ohmic contact layers.

We first grew a GaN buffer layer deposited at 500°C and a 1-µm-thick undoped GaN at 1000°C on c-face sapphire substrates. Then, we grew Mg doped GaN at 1000°C or Mg-doped $In_{0.14}Ga_{0.86}N$ or $In_{0.14}Ga_{0.86}N$/GaN SLs at 780°C. The sample structure of Mg-doped InGaN and SLs is schematically shown in Fig. 1. The source materials were triethylgallium, trimethylindium and NH_3 with N_2 as a carrier gas for the InGaN growth. The p-type dopant source was bis-cyclopentadienylmagnesium. All the samples were annealed at 700°C in N_2 ambience after the growth. Ni/Au (20 nm/20 nm) metal was deposited using electron beam evaporation system. The hole concentrations of the Mg-doped GaN, $In_{0.07}Ga_{0.93}N$, $In_{0.14}Ga_{0.86}N$ and $In_{0.14}Ga_{0.86}N$/GaN SLs were 6.9×10^{17}, 2.7×10^{18}, 6.7×10^{18} and 2.1×10^{19} cm^{-3}, respectively.

The specific contact resistances(ρ_c) were characterized by current-voltage (I-V) measurements based on the circular transmission line model (CTLM). The CTLM pattern was designed with a constant inner radius (r_{in}=50 µm) and spacings (d) from 10 to 70 µm. Figure 2 shows the typical CTLM I-V characteristics of the Mg-doped GaN. Linear I-V characteristics indicated that the good ohmic contacts were achieved in our process. Figure 3 shows the total resistance (R) as a function of $ln((r_{in}+d)/r_{in})$. The data of R were determined by the CTLM I-V characteristics as shown in Fig. 2. Since the I-V curves of all samples showed linear behavior, we could determine ρ_c from the data in Fig. 2. Table I shows ρ_c of the Mg-doped GaN, $In_xGa_{1-x}N$ (x=0.07, 0.14) and $In_{0.14}Ga_{0.86}N$/GaN SLs. While ρ_c of Mg-doped GaN is 1.1×10^{-2} Ωcm^2, ρ_c of Mg-doped InGaN and SLs are $1 \sim 3 \times 10^{-3}$ Ωcm^2. These lower ñ$_c$ of the Mg-doped InGaN system are ascribed to narrower E_g and higher acceptor concentrations in InGaN [4] and InGaN/GaN SLs.

These results indicate that the Mg-doped InGaN system is promising for lowering the p-type contact resistance. Further optimization of metallization schemes and surface treatment will improve ohmic contact characteristics, resulting in high device performance and reliability.

1) *for example*, H. Ishikawa, S. Kobayashi, Y. Koide, S. Yamasaki, S. Nagai, J. Umezaki, M. Koike and M. Murakami, J. Appl. Phys., **81** (1997) 1315.

2) L. Zhou, A. T. Ping, F. Khan, A. Osinsky and I. Adesida, Electron. Lett. **36** (2000) 91.

3) K.Kumakura, T. Makimoto and N. Kobayashi, Jpn. J. Appl. Phys. **39** (2000) L195.

4) K. Kumakura, T. Makimoto and N. Kobayashi, Jpn. J. Appl. Phys. **39** (2000) L337.

5) M. E. Lin, F. Y. Huang and H. Morkoç, Appl. Phys. Lett. **64** (1994) 2557.
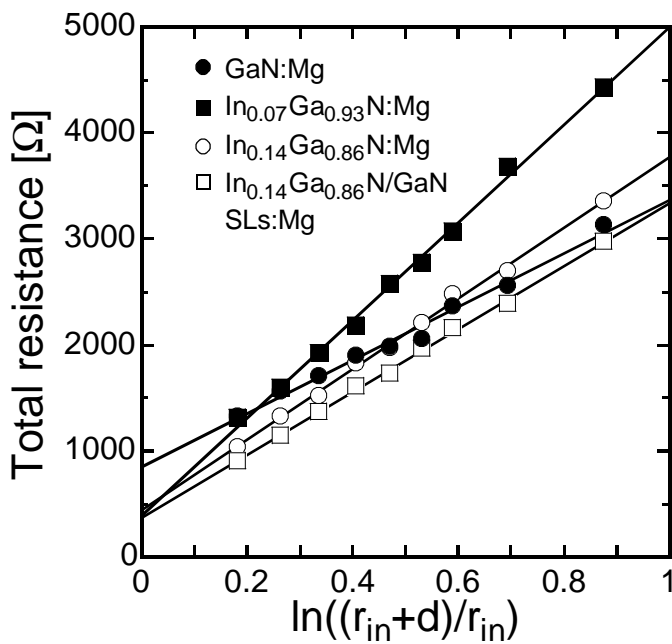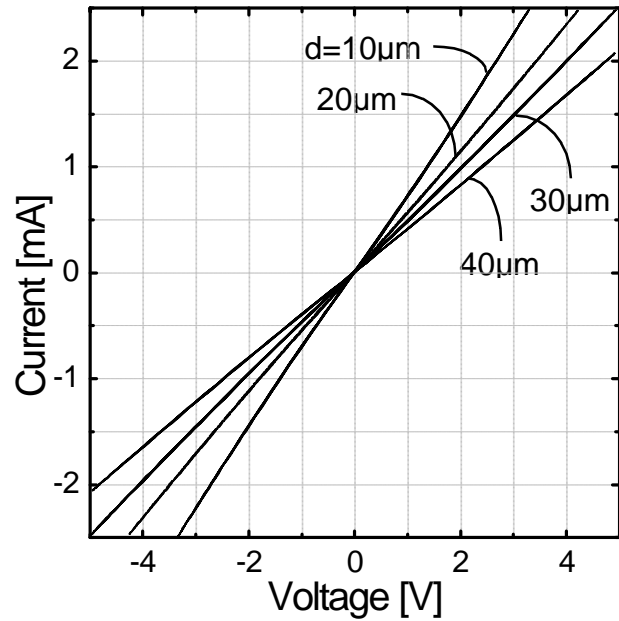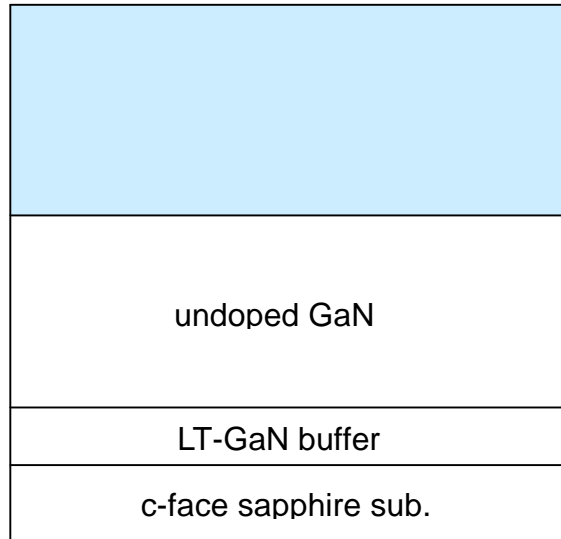
Mg-doped samples	Specific contact resistance [Ωcm^2]
GaN	1.1×10^{-2}
$In_{0.07}Ga_{0.93}N$	1.4×10^{-3}
$In_{0.14}Ga_{0.86}N$	2.3×10^{-3}
$In_{0.14}Ga_{0.86}N/GaN$ SLs	1.9×10^{-3}